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CLEANING TESTS OF CENTRAL ILLINOIS COAL

BY

THOMAS FRASER and H. F. YANCEY

This paper represents work done under a cooperative agreement between the Bureau of Mines, Department of the Interior, the State Geological Survey Division of the State of Illinois, and the Engineering Experiment Station of the University of Illinois

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By Thomas Fraser and H. F. Yancey

INTRODUCTION

GENERAL STATEMENT

Illinois coal producers have contributed much to the development of better preparation of bituminous coal for the market. More careful sizing and hand picking, and the early introduction of the shaker screen and the rescreening plant have evidenced this development. Mechanical processes of coal cleaning have aroused much interest, although actual construction of cleaning plants has been rather sporadic. Until recently progress of this kind has been slow because of the lack of interest among the consumers rather than the producers of coal.

In recent years higher freight rates have been largely responsible for a growing demand for cleaner coal, especially from outlying markets. So far as Illinois coal is concerned this demand comes for the most part from the northwest States. A condition more conducive to profitable washery operation is resulting, and is reviving the interest of Illinois operators in coal-cleaning processes. It is believed that a period of washery building will follow because natural conditions tend to bring about the introduction of better methods of preparation. These conditions include severe competition for markets and the production of a coal in which the impurities concentrate in the small sizes where they can not be removed by hand picking. For this reason much of the Bureau of Mines experimental work on the beneficiation of the coals of the eastern and interior fields has been done in Illinois.

As an integral part of this experimental work, the bureau, in cooperation with certain Illinois operators, has studied the problem of cleaning the No. 6 coal mined in central Illinois; that is, in Sangamon, Christian, Montgomery, and Macoupin Counties. Results of this particular part of the investigation are published for the double purpose of making the information available to those operators of the district who may be interested in immediate application

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of the results and of giving a practical illustration of the methods of examination partly described in earlier publications.[1]

A number of washing plants have been built in this district and several are in operation at present, but no new ones have been erected recently. The complete descriptive list of washeries in the State, compiled by F. C. Lincoln,[2] therefore covers central Illinois washery construction up to 1924. Although several such plants have been operated more or less continuously and satisfactorily to the present time, the small premium heretofore paid for washed coal has often made it unprofitable to clean the coal as completely as would be possible if the price justified.

SPECIFIC OBJECTS OF THE INVESTIGATION

The immediate purpose of this investigation was to determine the feasibility of cleaning the smaller sizes of coal produced in the central Illinois field so that in periods of normal and abundant coal supply these products might compete more successfully with similar sizes of coal from other mining fields, and thus insure for operators and mine workers of this district more continuous and dependable operation. The small coal marketed from the central or Springfield district is usually several per cent higher in ash content than the larger sizes, probably because of the occurrence in the seam of intruded and interbedded impurities that break up into comparatively small fragments in mining. This fact is particularly true of nut coal and screenings, and constitutes a great handicap to the steam sizes from this district. To remedy this condition operators in the central district are turning to better preparation of small coal.

An official of one of the operating companies has said that the aim in cleaning this coal should be to obtain, if possible, a washed product with an ash content of about 10 per cent. If this can be accomplished with a washer loss of 15 to 20 per cent, it is believed that the operation will be profitable. The production of cleaner screenings will have two advantages—a readier sale of screenings for chain-grate fuel and the probable opening of other markets for sized washed coal (Nos. 2, 3, and 4 washed nut) at higher prices than are obtained for unsized screenings.

Because the funds available for this particular work were small, it was not feasible to make a general investigation of the entire district, which includes mines working the Nos. 5 and 6 beds.

[1] Fraser, Thomas, and Yancey, H. F., Some factors that affect the washability of a coal: Trans. Am. Inst. Min. Eng., vol. 63, 1920, pp. 768–778; Interpretation of results of coal-washing tests: Trans. Am. Inst. Min. and Met. Eng., vol. 69, 1923, pp. 447–469.

[2] Lincoln, F. C., Coal washing in Illinois: Univ. of Illinois Eng. Exper. Sta. Bull. 69, 1913, 110 pp.

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Studies were therefore made at one of the larger mines in Montgomery County, working the No. 6 coal, which was selected as representative of this part of the district.

Raw screenings from this district generally carry 13 to 16 per cent and occasionally up to 20 per cent of ash. Specifically, therefore, the problem is to produce a dependably uniform washed coal product containing about 10 per cent ash from a raw coal that averages probably between 14 and 15 per cent ash but fluctuates between 13 and 20 per cent, and to obtain this reduction in ash content with not more than 20 per cent shrinkage.

DESCRIPTION OF THE COAL BED

Like all the mines in Montgomery, Macoupin, and Christian Counties and the southern part of Sangamon County, the mine studied works the No. 6 coal, the same that is mined in the Franklin-Williamson County field. The bed is about 100 inches thick at the mine examined. The principal continuous interbedded impurities are the blue band, characteristic of No. 6 coal throughout both fields, and the somewhat similar steel band, near the roof, which characterizes this seam in the central field. The location of the bands is shown in Figure 1, *A* and *B*, which gives the vertical section of the bed at two of the four places where face samples were taken. These sections also show a number of smaller and less continuous partings in the seam at these particular places. The samples and face-section logs obtained in various mines of the district show that the mode of occurrence of the impurities is much the same in the No. 6 bed throughout the field. These data may be found in Bureau of Mines publications[3] on analysis of coal samples. Figure 1, *C*, is a section that shows impurities in the seam in a mine near Staunton, Macoupin County, and Figure 1, *D*, is a section taken at Panama, Christian County. These sections are similar to sections *A* and *B*, which give the conditions in the mine actually examined. Lenses of pyrite from ¼ to 1 inch thick are a characteristic feature of the bed and occur promiscuously throughout it. Although these lenses comprise by far the greater part of the pyrite in the seam, some thin plate-like pyrite is present. Flakes of gypsum and calcite also occur frequently. These various partings are the chief sources of the free dirt found in the coal as marketed. The thin partings and lenses and small fragments of the thicker bands, which are not removed in picking, concentrate in the smaller sizes.

[3] Lord, N. W., Holmes, J. A., Stanton, F. M., Fieldner, A. C., and Sanford, Samuel, Analyses of coals in the United States: Bull. 22, Bureau of Mines, 1913, pp. 498–500; Fieldner, A. C., Smith, H. I., Paul, J. W., and Sanford, Samuel, Analyses of mine and car samples of coal collected in the fiscal years 1913–1916: Bull. 123, Bureau of Mines, 1918, pp. 177–178.

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At this mine four sizes of coal are usually made—lump, egg, nut, and screenings. For October, 1922, the percentage of each size was as follows:

Proportion of sizes made

Size	*Per cent*
Lump, over 6 inches	29.6
Egg, 3 to 6 inches	17.3
Nut, 2 to 3 inches	12.9
Screenings, under 2 inches	40.2

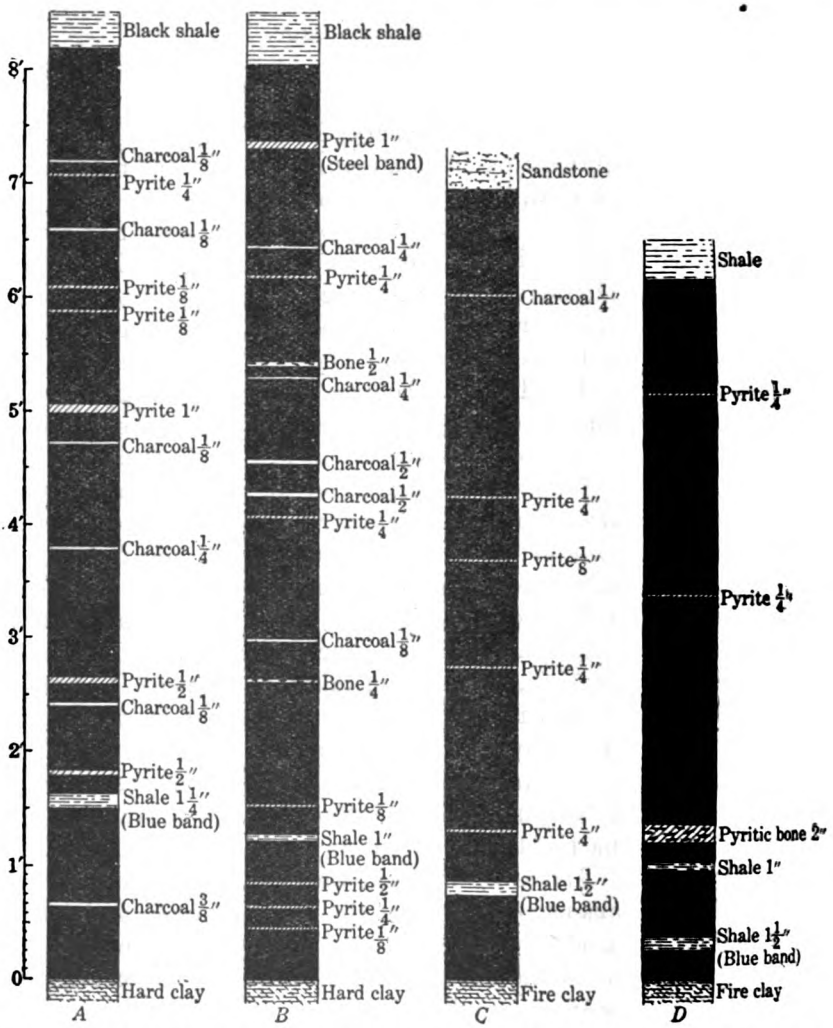

FIGURE 1.—Face sections of No. 6 coal in central Illinois: *A* and *B*, sections in mine examined (Montgomery County); *C*, section in Macoupin County at Staunton; *D*, section in Christian County near Panama

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Round-hole punched-plate screens are used. The two smallest sizes (nut and screenings) which need cleaning amount to a little more than half the total output.

METHOD OF EXAMINATION

To ascertain the sources of the impurities to be removed, the seam was examined at four places near the faces of the main haulage entries, in the four quarters of the mine. The thickness and location of partings and the material in them were noted and two face samples taken at each place; one sample included the coal and all impurities in the coal section as shown in Figure 1 and the other excluded all segregated impurities one-eighth inch or more thick.

For the washing tests, samples of the screenings and the nut coal were taken continuously during three days' operation. In this way a 25-ton car was loaded with about 10 tons of nut coal and 15 tons of screenings. During these three days 11,627 tons of coal were hoisted—an average of 3,875 tons a day.

In order to show what fluctuation might be expected in the ash and sulphur content of raw material fed to a washery, 12 individual car samples were taken at intervals during the three days on which the large samples were collected for washing tests. These car samples were taken as prescribed by the Bureau of Mines for tipple sampling.

The experimental work on these samples was performed in the laboratory of the department of mining engineering, University of Illinois. Screening tests of samples of raw screenings, complete specific gravity analyses of samples of raw screenings and raw nut coal, jig-washing tests of screenings and nut coal, a table-washing test of slack coal (fine dust to ¼ inch), and a sizing test of washed screenings were made.

The data reported in this paper indicate what results may reasonably be expected from washing the coal mined in this field, in so far as the samples tested represent average conditions. Although it is believed that the coals tested are representative, in practice the amount of dirt in the raw coal produced will fluctuate widely, causing variations in current washery performance. The yield of washed coal will be the main item affected because the large fluctuations in the character of the raw coal are usually due to the proportion of coarse removable impurities.

CHARACTERISTICS OF RAW COAL

PHYSICAL FORM OF IMPURITIES

Face samples show about the following analysis for No. 6 coal in this district: Moisture, 12 to 14 per cent; volatile matter, 40 to 42

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per cent; fixed carbon, 46 to 49 per cent; ash, 10 to 13 per cent; sulphur, 3 to 5 per cent; and B. t. u., 12,000 to 12,600. All the figures except that for moisture are on a dry basis. The four sections of the bed already pictured in Figure 1 (p. 4) probably represent average conditions and explain the origin of the dirt the coal contains when it reaches the tipple. Of these impurities the blue band usually, and the steel band sometimes, break out free and clean during mining; and what is not broken into small pieces may be picked out by the miners. Fragments of the blue band and steel band and of the larger pyrite lenses probably make up most of the clean heavy refuse in the nut coal and the screenings. This refuse is readily identified in the tipple, especially in the nut coal.

The thin irregular binders and lenses distributed promiscuously through the seam are generally attached firmly to the adjacent coal and in breaking them up cleavage does not occur between the coal and the dirt, but usually in the coal. The fragments of these binders will, therefore, go to the cleaning plant with more or less coal adhering, constituting mixed particles or middlings in the feed unless crushed comparatively fine. Material of this kind is much in evidence, especially in the nut coal, the most common form being pieces of good coal with thin bands of pyrite attached.

Other impurities include clay binders and "rashy" bands (mixtures of carbonaceous shale and charcoal) which are very friable. When treated by the wet process, these impurities by attrition in the jigs break down into slime that goes into the hutches and the washed coal sludge. Disintegration of some of the shales was noted even when the float-and-sink tests were being made.

ASH AND SULPHUR CONTENT

Table 1 gives the ash and sulphur figures for the face samples taken in the four sections of the mine. Two samples were taken at each place, one including all impurities and the other excluding all impurities that were believed to be removable by washing. These figures show that the complete vertical section, including all bands, averages about the same in ash content as the raw screening produced in the tipple; and the clean coal excluding all segregated impurities has about the quality (with respect to ash content) desired in the washed-coal product.

TABLE 1.—*Percentage of ash and sulphur in face samples, moisture-free basis*

Entry	Clean coal			Entire seam	
	Face moisture	Ash	Sulphur	Ash	Sulphur
First air course, main southeast	12.77	9.7	3.91	12.3	4.42
Face, main northwest	11.97	11.8	4.21	17.7	6.09
Face, main northeast	12.06	11.1	4.48	18.0	7.82
Twelfth left off main southwest	12.43	11.0	4.26	15.6	6.40

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The large three-day samples of nut coal and screenings taken for washing tests analyzed 14.3 per cent ash and 5.73 per cent sulphur for the nut size, and 14.3 per cent ash and 5.06 per cent sulphur for the screenings size. Previous figures show about the same or a somewhat higher ash content in the screenings, but probably no sampling as extensive as this had been undertaken before.

Analyses of the 12 individual car samples of screenings taken at intervals during the three days covered by the sampling operation are given in Table 2. These analyses show an ash content ranging from 13.6 to 18.2 and a sulphur content ranging from 4.80 to 5.91 per cent. Most of these samples were higher in ash than the general sample used for washing tests, but the mean of these 12 samples could hardly be expected to represent the output, as they were taken from only 12 out of the 101 cars loaded during the three days' operation. As a further index to the fluctuations in ash and sulphur content of the coal produced from the No. 6 seam throughout the central Illinois field, a number of tipple and car samples taken at other mines are included in the table. These figures are taken from Bureau of Mines Bulletins 22 and 123.

TABLE 2.—*Percentage of ash and sulphur in 12 car samples of screenings*

Sample	Moisture	Moisture-free basis	
		Ash	Sulphur
1 Screenings		14.30	5.24
2 Screenings		14.50	5.53
3 Screenings		15.20	5.62
4 Screenings		15.10	5.12
5 Screenings		15.90	5.19
6 Screenings		13.60	4.80
7 Screenings		17.70	5.09
8 Screenings	12.3	15.10	5.15
9 Screenings	10.1	14.80	5.31
10 Screenings	12.0	18.20	5.91
11 Screenings	11.9	14.30	5.10
12 Screenings		15.00	5.03
Staunton screenings [a]		16.03	4.55
Staunton slack [a]		18.11	4.50
Staunton r. o. m. [a]		12.42	4.66
Livingston screenings [b]		18.41	4.80
Collinsville r. o. m. [a]		14.78	5.08
Collinsville nut [a]		19.55	4.97
Gillespie r. o. m [c]		15.11	5.76

[a] Lord, N. W., and others, Analyses of coals in the United States: Bull. 22, Bureau of Mines, 1913, p. 86.
[b] Lord, N. W., and others, work cited, p. 87.
[c] Fieldner, A. C., and others, Analyses of mine and car samples of coal collected in the fiscal years 1913 to 1916: Bull. 123, Bureau of Mines, 1918, p. 34.

FORMS OF SULPHUR

The different sulphur compounds present were determined in the raw screenings, in the raw nut coal, in the raw slack (0 to ¼ inch part of screenings), and in the washed coal obtained in the final jig test of the screenings. In addition, the amount of finely disseminated pyritic sulphur was determined in the raw slack. The values

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found for total sulphur, pyritic sulphur, and organic sulphur are shown in Table 3. The figures for sulphate sulphur are not recorded in the table but are as follows: Screenings, 0.04 per cent; slack, 0.25 per cent; and nut coal, 0.04 per cent. The slack is higher than the other samples, probably because oxidation of the pyrite proceeded more rapidly in the smaller sizes during the period which elapsed between the sampling and analysis; or because the flakes of gypsum from the screenings were concentrated in the slack.

TABLE 3.—*Percentage of various forms of sulphur in the coal, moisture-free basis*

Sample	Total sulphur	Pyritic sulphur	Organic sulphur	Organic, as per cent of total
	Per cent	*Per cent*	*Per cent*	*Per cent*
Raw screenings	5.16	2.76	2.36	45.7
Do	4.97	2.53	2.40	48.3
Raw slack	4.90	2.30	2.35	48.0
Raw nut	5.73	3.31	2.38	41.5
Washed screenings	4.26	1.80	2.46	57.7

Table 3 shows that this coal is high in organic sulphur; the raw screenings contain 2.40 per cent of sulphur in this form. The proportion of fine disseminated pyritic sulphur in the slack was estimated by the method previously published[4-5] as 0.88 per cent. Neither organic sulphur nor fine disseminated pyritic sulphur can be removed from coal by any practicable commercial process. As this coal contains 2.4 per cent of organic sulphur and nearly 1 per cent of fine pyritic sulphur, production of a clean coal containing less than 3.4 per cent of sulphur is evidently not practicable.

SCREEN ANALYSES

With regard to the proportion of sizes present in the screenings from this mine and the distribution of impurities in the various sizes, screening tests showed increasing ash content with decreasing size of particles, but no marked difference in the sizes larger than one-sixteenth inch. Similar distribution of the impurities as to size is indicated by the results of screening tests of a sample of screenings from this field made in 1915 by E. A. Holbrook.[6]

For these screening tests a representative sample of 1,320 pounds was used and sizing of the fines was carried down to one-sixty-fourth-inch round hole. Concentration of the dirt in these fine sizes is a condition unfavorable to the best cleaning results, because the fine material is the most difficult to clean; and, in the jigging of a natural

[4-5] Yancey, H. F., and Fraser, Thomas, The distribution of forms of sulphur in the coal bed: Univ. Illinois Eng. Exper. Sta. Bull. 125, 1921, p. 23.

[6] Holbrook, E. A., Dry preparation of bituminous coal at Illinois mines: Univ. Illinois Eng. Exper. Sta. Bull. 88, 1916, pp. 122–123.

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feed of wide range in size, little or no cleaning effect is ordinarily expected in the sizes below about one thirty-second inch. The proportion of fines in this sample, however, is comparatively small, as shown by the small amount (6.89 per cent) that passed through a one-thirty-second-inch round-hole screen. This dust usually is not improved by washing and its presence increases the difficulty of dewatering the washed coal and clarifying the circulating wash water, hence removal of the dust before washing is often desirable.

TABLE 4.—*Screen analysis of raw screenings, moisture-free basis*

Size of round-hole screen, inches	Weight	Amount	Ash	Sulphur
	Pounds	*Per cent*	*Per cent*	*Per cent*
On 1¼	176.0	13.34	12.7	5.15
Through 1¼ on 1	215.0	16.29	13.2	5.65
Through 1 on ¾	139.0	10.53	13.2	5.37
Through ¾ on ½	227.5	17.23	13.6	5.61
Through ½ on ¼	231.0	17.50	13.2	5.14
Through ¼ on ⅛	128.5	9.73	14.3	5.04
Through ⅛ on 16	59.5	4.50	15.7	5.00
Through 16 on 32	52.7	3.99	18.6	4.73
Through 32 on 64	34.5	2.61	21.1	4.60
Through 64	56.5	4.28	18.8	4.80
Total	1,320.2	100.00		
Average			14.1	5.27
Total through ¼ inch	331.7	25.10	17.0	4.90

SPECIFIC GRAVITY ANALYSES

A specific gravity analysis of a representative sample is a valuable indication of the washability of a coal. In such an analysis the material is graded with regard to the specific gravity of the particles by a float-and-sink test with a series of heavy solutions. The impurities concentrate in the heavier fractions and the clean coal in the lighter fractions.

In the examination of this coal such determinations were made with samples of all sizes—screenings, nut, slack, or No. 5 (fine dust to ¼ inch), and a composite of the small nut sizes (¼ to 2 inches).

TABLE 5.—*Specific gravity analysis of screenings, moisture-free basis*

Specific gravity	Weight, grams	Per cent	Cumulative per cent	Ash		Sulphur	
				Per cent	Cumulative per cent	Per cent	Cumulative per cent
Float on 1.25	1,651	3.52	3.52	5.0	5.0	3.44	3.44
1.25 to 1.30	7,905	16.83	20.35	5.3	5.3	3.45	3.45
1.30 to 1.35	25,081	53.37	73.72	9.3	8.2	3.81	3.70
1.35 to 1.40	3,052	6.50	80.22	14.7	8.7	4.62	3.78
1.40 to 1.45	1,554	3.31	83.53	19.6	9.2	5.62	3.85
Raw dust *	1,940	4.13	87.66	21.7	9.7	4.28	3.87
1.45 to 1.50	781	1.66	89.32	23.0	10.0	6.63	3.92
1.50 to 1.60	1,030	2.19	91.51	28.2	10.4	7.96	4.02
1.60 to 1.80	1,376	2.71	94.22	39.0	11.2	8.34	4.14
Sink in 1.80	2,722	5.78	100.00	66.4	14.4	17.08	4.94
Total heads	46,992	100.00		14.4		5.06	

* Dust removed from sample before specific gravity analysis; is material through 65-mesh, from screenings.

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The free, clean, removable dirt particles appear in the fraction heavier than 1.80 specific gravity, and easy washing depends on the concentration of a large proportion of the impurities in this form. The intermediate fractions, between say 1.40 and 1.80, are more difficult and less profitable to remove because some combustible is carried into the refuse and lost, and because the reduction in ash content of the remaining clean coal by the removal of a given amount of this middling material is relatively small.

COMPOSITION OF SCREENINGS

The composition of the screenings with respect to specific gravity is shown graphically in Figure 2. This coal contains a rather large proportion of middling material, and to produce without prohibitively large losses a washed coal as low in ash as the float on 1.35

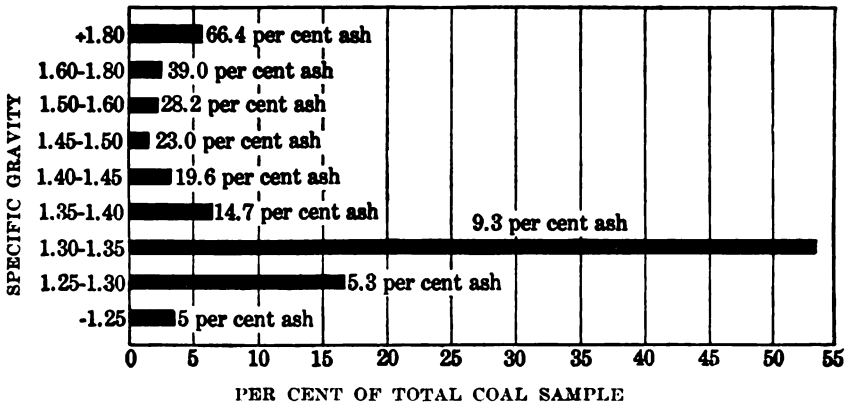

FIGURE 2.—Specific gravity fractions in raw screenings

specific gravity solution would be impossible. There is, however, a large proportion of impurities in the two heaviest fractions, 1.60 to 1.80 and heavier than 1.80, the removal of which would result in reduction of the ash content to about the amount desired in the washed coal.

TABLE 6.—*Specific gravity analysis of screenings over a one-quarter-inch round-hole screen, moisture-free basis*

Specific gravity	Weight, grams	Per cent	Cumulative per cent	Ash		Sulphur	
				Per cent	Cumulative per cent	Per cent	Cumulative per cent
Float on 1.25	538	1.64	1.64	4.3	4.3	3.62	3.62
1.25 to 1.30	6,723	20.56	22.20	5.2	5.1	3.46	3.50
1.30 to 1.35	19,119	58.46	80.66	10.2	8.8	3.92	3.79
1.35 to 1.40	1,442	4.41	85.07	16.1	9.2	3.34	3.77
1.40 to 1.45	915	2.80	87.87	21.8	9.6	6.18	3.84
1.45 to 1.50	463	1.41	89.28	24.7	9.8	7.25	3.90
1.50 to 1.60	768	2.35	91.63	28.6	10.3	8.47	4.02
1.60 to 1.80	917	2.80	94.43	39.5	11.2	9.13	4.17
Sink in 1.80	1,822	5.57	100.00	64.1	14.1	20.79	5.09

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TABLE 7.—*Specific gravity analysis of slack coal (fine dust to ¼ inch), moisture-free basis*

Specific gravity	Weight, grams	Per cent	Cumulative per cent	Ash		Sulphur	
				Per cent	Cumulative per cent	Per cent	Cumulative per cent
Float on 1.25	1,113	9.02	9.02	5.3	5.3	3.35	3.35
1.25 to 1.30	1,182	9.58	18.60	6.2	5.8	3.37	3.36
1.30 to 1.35	5,491	44.48	63.08	6.5	6.3	3.48	3.44
1.35 to 1.40	1,610	13.04	76.12	10.8	7.1	3.98	3.53
1.40 to 1.45	639	5.18	81.30	16.3	7.6	4.82	3.62
1.45 to 1.50	318	2.57	83.87	20.6	8.0	5.74	3.68
1.50 to 1.60	262	2.12	85.99	27.2	8.5	6.50	3.75
1.60 to 1.80	359	2.91	88.90	37.8	9.5	6.31	3.84
Sink in 1.80	1,371	11.10	100.00	71.2	16.4	12.17	4.76

The cumulative figures for yield ash and sulphur have been plotted in Figures 3, 4, and 5. These yield-ash curves and yield-sulphur curves show the yield of any desired grade of coal between 5 and

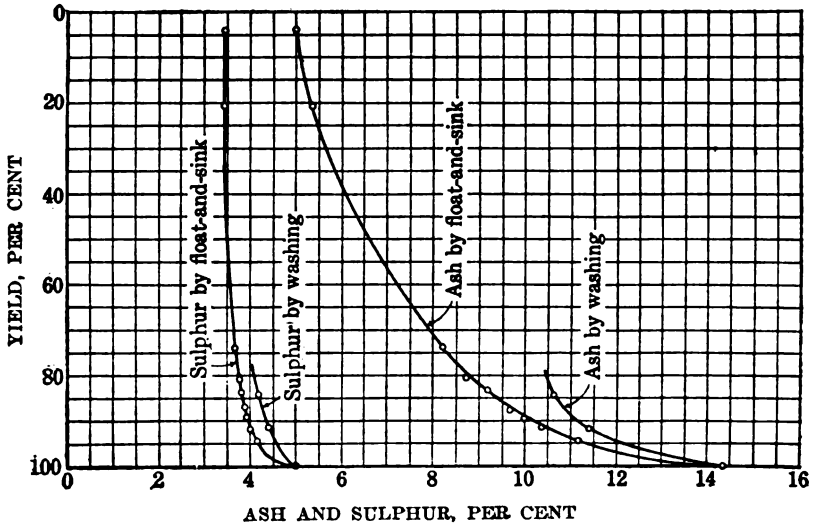

FIGURE 3.—Yield curves for screenings

14.4 per cent ash obtainable from screenings by the float-and-sink process. Figure 3 shows a yield (from the unsized screenings) of 89.3 per cent of float coal containing 10.0 per cent ash by separation at a specific gravity of 1.50. For the objects in view, as outlined in the introduction, this separation was selected as the most profitable one to make, and the attempt was made to duplicate these results in the washing tests. Complete specific gravity separation can not be expected in a commercial plant, but a well-adjusted plant adapted to the coal should come within a few per cent of the separation

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desired. A specific gravity separation of this kind is generally used as a standard for determining the efficiency of the cleaning operation. On the nut-coal separation a specific gravity of 1.60 was

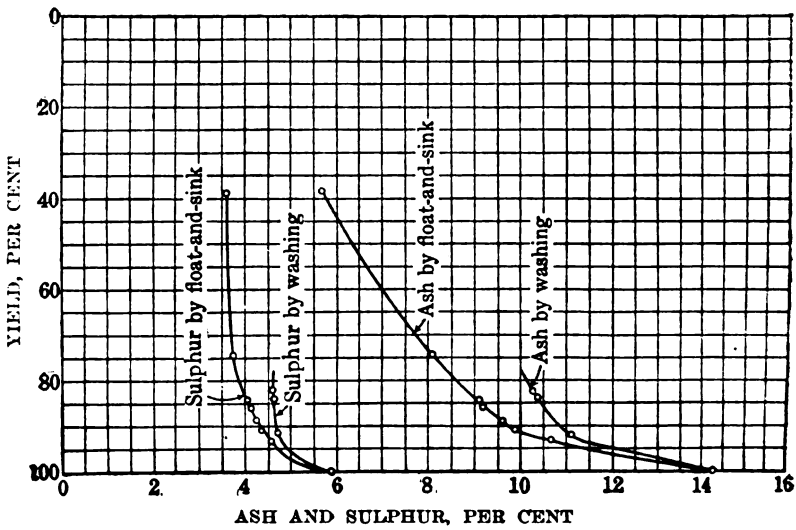

FIGURE 4.—Yield curves for nut coal

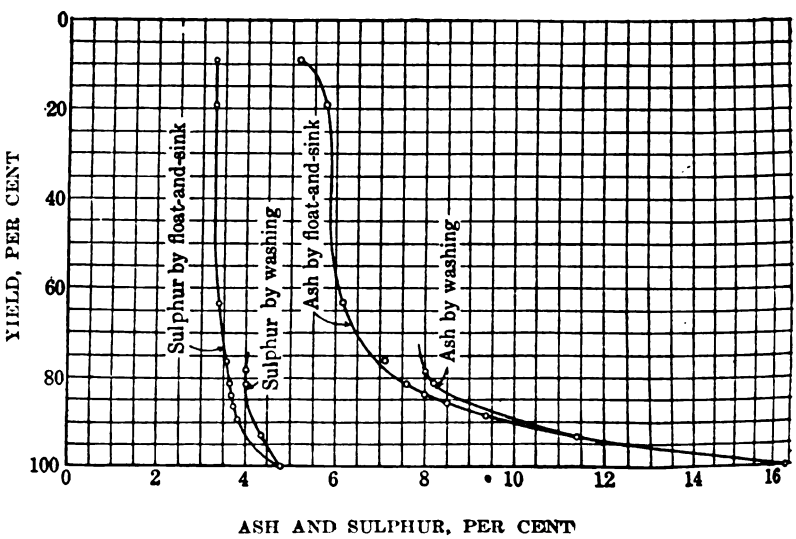

FIGURE 5.—Yield curves for slack

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selected as the most profitable to duplicate. It would result in a yield of 90.44 per cent with an ash content of 9.9 per cent.

TABLE 8.—*Specific gravity analysis of nut coal, moisture-free basis*

Specific gravity	Weight, grams	Per cent	Cumulative per cent	Ash		Sulphur	
				Per cent	Cumulative per cent	Per cent	Cumulative per cent
Float on 1.30	33,521	37.87	37.87	5.7	5.7	3.64	3.64
1.30 to 1.35	32,368	36.80	74.67	10.5	8.1	4.11	3.87
1.35 to 1.40	8,824	9.97	84.64	15.9	9.1	5.40	4.06
1.40 to 1.45	1,306	1.47	86.11	18.5	9.2	7.40	4.11
1.45 to 1.50	2,280	2.57	88.68	23.9	9.6	5.82	4.21
1.50 to 1.60	1,555	1.76	90.44	25.2	9.9	11.62	4.36
1.60 to 1.80	2,216	2.51	92.95	38.5	10.7	10.36	4.52
1.80 sink	6,226	7.05	100.00	62.6	14.3	23.35	5.84

ESTIMATING WASHERY PERFORMANCE BY MEANS OF THE FLOAT-AND-SINK TEST

DIFFICULTIES ENCOUNTERED

In the preliminary examination of a coal by the float-and-sink method, interpretation of the results of the float-and-sink test or estimation of probable washery performance by means of these tests is at once the most essential and the most difficult step to take. Obviously there is no mathematically precise method for making this transition of figures from practically complete specific gravity separation to the approximation of this condition attainable in commercial operation. This final interpretation is purely an estimate that must be made empirically; its value therefore depends on the skill and judgment of the examining engineer. Without such an estimation, however, the float-and-sink test is of little value as a method of preliminary examination of a raw coal; when this step is omitted, as it is sometimes, any conclusion may be very misleading.

For these reasons this feature has been made the major study in the float-and-sink research incident to the coal-washing investigations, of which the work with central Illinois coal is a part. In a long series of washing tests an attempt has been made to accumulate enough comparable data on float-and-sink yields and corresponding washery yields for the same coal to establish an approximate value for the factor by which the float-and-sink results must be adjusted in order to forecast washery results safely. Some of these comparative figures have been presented in earlier publications already cited.

Other investigators, notably Drakeley[7] and Delamater,[8] have done valuable work looking toward the establishment of a relation be-

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tween washing results and float-and-sink results, but they have attacked the problem from the washery end to determine operating efficiencies. This calculation might now be reversed and the efficiency member used in calculating the washery yield from the float-and-sink yield, if the proper value for this efficiency rating could be established for any given coal under consideration. This feature is the most vital and the most difficult phase of this examination method. Even if the accumulated data on a number of other coals are at hand, they are at best but an approximation, and the probable error in this step is greater than any combination of errors likely to occur in the float-and-sink test itself when made with reasonable care.

METHOD OF ESTIMATION RECOMMENDED

When washery performance is compared with float-and-sink separation, the simplest method is to determine the relative yields of clean coal product of a given ash content. This ratio is the efficiency number for the washery operation as determined by the yield-curve method.[9]

This ratio has been found to range from 99 per cent in some tests of easily washed coals, where removal of only the clean heavy rock was desired, to as low as 75 per cent in tests of bony coals where a very clean washed-coal product was desired. Washery performance might be calculated from the float-and-sink yield curve by ascertaining from this curve the yield of float coal of the desired quality, and multiplying this yield figure by an assumed efficiency number.

WASHING YIELD CURVES

A more satisfactory procedure, however, is to sketch in a hypothetical washing yield curve, to the right of the float-and-sink yield curve, similar (in shape and relation to the float-and-sink curve) to the washing yield curves obtained from other coals of the same type, if any are available. Such a set of yield curves, obtained in washing tests of samples of the No. 6 coal from Williamson County, are shown in Figure 6. This bed is the same as that mined in the central Illinois field and the coal is somewhat similar in the occurrence and distribution of impurities. It contained a considerable proportion

[7] Drakeley, T. J., Coal washing: A scientific study: Trans. Inst. Min. Eng., vol. 54, 1917–1918, pp. 418–459; Coal washing: Further scientific studies: Trans. Inst. Min. England, vol. 59, 1919–1920, p. 86.

[8] Delamater, G. R., Coal washing efficiency calculations: Coal Age, vol. 5, 1914, pp. 723–729.

[9] Fraser, Thomas, and Yancey, H. F., Interpretation of results of coal-washing tests: Trans. Am. Inst. Min. and Met. Eng., vol. 69, 1923, p. 459.

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of middling material and may be considered about average grade in washability.

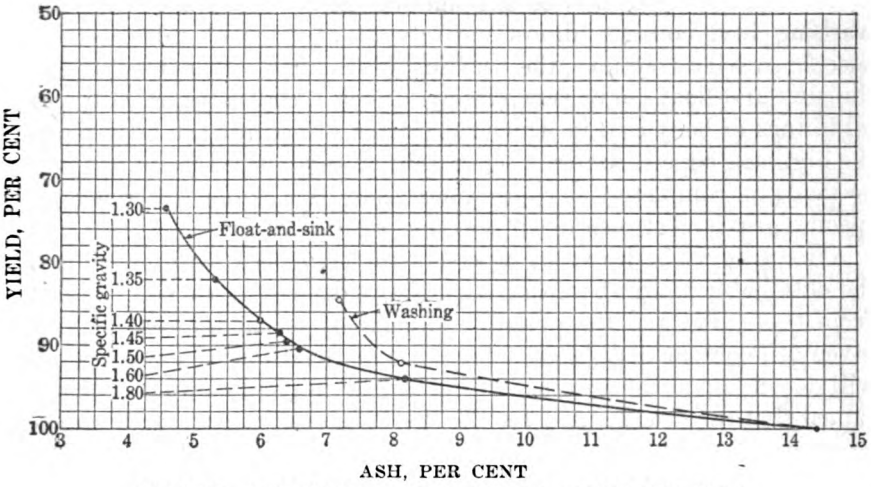

FIGURE 6.—Typical float-and-sink yield and washing yield curves

Different coals have widely varying characteristics, and the shape of the yield curves will therefore vary. The functional relation of the actual washing curve to the float-and-sink curve is not as uncertain as might be expected, however, because the latter is itself the characteristic curve of the coal and evaluates the chief factor that affects the washability of the coal, namely, the distribution of impurities with respect to specific gravity. Any such pair of curves evidently will have a common point at 100 per cent yield and the two curves will diverge as they extend up into the area representing separation at low specific gravities.

When an assumed washing-yield curve is drawn in it should be noted that this divergence, or the distance between the two curves at any point, depends upon specific gravity rather than upon position with respect to the percentage yield scale. Thus when a coal is easily washed, has very little middlings, and practically all the impurities are in the form of clean heavy rock, the high specific gravity part of the curve, which lies close to the float-and-sink yield curve, will be elongated and will be the part of the curve used. Almost complete specific gravity separation of such a coal is possible with commercial machines. Washing yield curve and float-and-sink curve will lie close together. On the other hand, the curves for a coal that contains practically no heavy rock but contains impurities in the form of light bone and carbonaceous shale, appear widely divergent because the lower high specific gravity sections will be greatly shortened and the more widely separated low specific gravity sections will be the prominent parts of the curves.

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CURVES FOR HIGH-ASH COALS

For coals of exceptionally high ash content with the ash finely divided and so disseminated throughout the coal substance that the washing feed consists almost entirely of a series of intermediate specific gravity fractions, the washing yield curve will not approach the sink-and-float curve very closely. Such a coal is practically all middlings or bony coal in which separation of the low-ash bone from the high-ash bone is desired; separation at any desired point can not be made as completely here as where there is a wider difference in specific gravity between clean coal and refuse products.

After a curve is drawn to represent the estimated washing yields, the obtainable yield of washed coal of any desired grade can be read from this curve and the probable amount of secondary coal of any given ash content may be calculated. The precision of these figures will depend upon the accuracy of the estimated yield curve if it be assumed that the sample used for the specific gravity analysis was representative of the raw coal that will be delivered to the proposed washery.

FLOAT-AND-SINK METHOD

To be sure that the sample used represents as nearly as possible the future washery feed is obviously difficult, yet is very important. The float-and-sink equipment ordinarily available necessitates the use of comparatively small samples, and even under the most favorable conditions, only a few hundred pounds can be so treated. When it is necessary to examine coal by the float-and-sink method and report on its washability without actually making washing tests, as is sometimes done because experimental washing equipment is not available, the samples used should be as large as can be handled, and a series of several samples taken in the tipple at intervals or in the mine at different places should be tested.[10]

Float-and-sink tests have one advantage over actual washing tests for determining the washability of a coal. The results are not influenced by such maladjustments as are difficult to eliminate in trial runs with actual coal-washing machines in which the operator has no way of determining definitely what kind of separation is being made until the test is completed and the analyses are made. For this reason float-and-sink data are often useful in adjusting washing-test results to the conditions desired in commercial operation; thus with one or two points on the washing yield curve fixed by actual washing tests, the complete curve can be projected following the

[10] Blythe, M. W., and O'Shea, L. T., The examination of a coal in relation to washing: Trans. Inst. Min. Eng., vol. 57, pt. 5, 1919, pp. 261–276.

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general shape of the float-and-sink yield curve. The yield of any desired quality of washed coal can thus be determined very accurately.

WASHING TESTS

EQUIPMENT

It is assumed that the logical operating method at any wet plant which may be built in the district to produce domestic and steam coal for the general market would be to wash the unsized screenings in jigs; or, as an alternative, to screen out the slack through a one-fourth or a three-eighths inch screen and treat it either on wet or dry tables. The washing tests were therefore made in that way. The data are equally applicable, however, to the design of a plant for treatment of the coal by other systems of gravity concentration, such as dry cleaning or a combination of wet and dry processes. The basis of all such processes is the difference between the specific gravity of coal and dirt. The specific gravity analyses curves, adjusted by a factor to allow for the losses commonly incurred in commercial treatment, show about what may be expected of any of these processes when correctly adjusted to the material being treated. Two tests of unsized screening samples of about 3 tons each were made with the Elmore jig and a small sample of the slack, sized to pass a one-fourth-inch round-hole screen, was washed on the table. One jig test of the nut coal was made. The jig used for testing both sizes of coal had two compartments, each of which was 18 inches wide by 30 inches long. The first compartment plunger was of the plain eccentric type, and the second compartment had an Elmore differential eccentric plunger.

TESTS OF SCREENINGS

The first jig test of the screenings was a preliminary run and the results were naturally rather unsatisfactory; but certain changes in the equipment were indicated which produced better results in the second test. Results of this final test are given in Table 9. The reader should note that because of the large proportion of pyrite, which loses one third of its weight in incineration, the refuse is cleaner than the ash figure indicates. The refuse from this test, for example, gave an analysis of 18.2 per cent sulphur—practically all of which was pyritic—and therefore contained approximately 34 per cent pyrite.

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TABLE 9.—*Final jig test of screenings, moisture-free basis*

Product	Weight	Feed	Ash [a]	Sulphur	B.t.u.
	Pounds	*Per cent*	*Per cent*	*Per cent*	
Raw coal	6,150.0	100.0	14.3	5.06	12,55
Washed coal	4,728.0	76.9	9.9	4.26	12,48
Sludge loss by difference [b]	467.0	7.6	19.8	4.15	
Middlings	154.5	2.5	23.0	6.12	
2d hutch	312.0	5.1	16.7	4.64	
Refuse	174.2	2.8	51.2	18.22	
1st hutch	314.0	5.1	37.9	7.55	
Total and average	6,149.7	100.0	14.3	4.87	
Washed coal and sludge	5,195.0	84.5	10.7	4.25	12,50
Washed coal, sludge, middlings, and 2d hutch	5,661.5	92.1	11.4	4.52	
Screen analysis of refuse:					
On ¼ inch	126.2	[c] 72.6	61.2	23.39	
Through ¼ inch	48.0	[c] 27.4	24.8	4.51	

[a] Softening temperatures of ash: Raw coal, 1,960° C.; washed coal, 2,060° C.
[b] Ash and sulphur content determined on sample of 0 to ¼ inch washed coal
[c] Percentage of each size in refuse.

The hutch products obtained in all the jig tests were rather unsatisfactory and doubtless contained more combustible than would be lost in these products in continuous commercial operation. An attempt was made to remedy this in the final test by bedding the jig with refuse before starting, deepening the jig bed somewhat, and maintaining a heavier refuse bed in the first compartment throughout the test; but the resulting first hutch product, although better than that obtained in the preliminary test, was still high in combustible, a fact that is probably due to the small size of the washed-coal settling tank. Coarse coal particles in the water that overflowed this tank and was pumped back into the jig boxes were probably concentrated to a certain extent in the hutches, which thus acted as traps for the larger coal particles in the circulating water.

FINAL TEST

The final test of the screenings gave a yield of 84.5 per cent of washed coal of 10.7 per cent ash content, including the sludge lost that should be saved in commercial operation by suitable equipment for sludge recovery and water clarification. In view of the large proportion of free coal lost in the hutch products, it is probable that a somewhat higher yield of washed coal of this grade can be obtained in commercial operation. A three-product separation was made in the tests to facilitate interpretation of the results; it gives enough data for plotting a yield curve by means of which intermediate points may be interpolated and the yield of washed coal of exactly the desired grade ascertained. Such yield curves for the screenings, slack, and nut-coal washing tests are given in Figures 3, 4, and 5.

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The secondary coal suitable for boiler fuel, consisting of the middlings and second hutch products, amounted to 7.6 per cent of the feed and had an ash content of 18.7 per cent. This amount could probably be decreased somewhat by recovery of free coal from the hutch, but would still be a larger product than could be used in the mine power plant. If a three-product separation is made in operation, therefore, some of the secondary coal should go into the washed coal. This test, however, came rather close to the separation which would probably be most profitable in operation, and shows the practicability of producing a washed coal of 10 to 11 per cent ash, amounting to 85 to 90 per cent of the raw feed. Combination of all the secondary coal with the washed coal to make a two-product separation shows a yield of 92.1 per cent of washed coal with an ash content of 11.4 per cent. The raw-coal screenings fed to the jig contained 9.7 per cent moisture, and the washed screenings (after being drained overnight in the bin) had 15.5 per cent moisture.

SIZING TEST

To ascertain the relative effectiveness of the jigging operation in cleaning the different sizes of material in the raw coal feed, and to determine the advisability of screening out the slack below one-fourth inch size and washing it separately on tables or of dedusting the feed and adding the dry untreated dust to the washed-coal product, a sizing test of the washed coal was made with the same screens as were used for the sizing test of the raw coal. Before the washed-coal screen analysis is interpreted in this way, it should be pointed out that due to the large loss of overflow sludge, which is therefore absent from the washed-coal sample used, there is a great possibility of error in assuming that the samples of the fine sizes (0 to $\frac{1}{64}$ inch and $\frac{1}{64}$ to $\frac{1}{32}$ inch) are representative.

TABLE 10.—*Screen analysis of raw and washed screenings, moisture-free basis.*

Size, round hole	Raw coal			Washed coal		
	Per cent	Ash	Sulphur	Per cent	Ash	Sulphur
On 1¼ inches	13.3	12.7	5.15	10.3	9.6	4.26
1 to 1¼ inches	16.3	13.2	5.65	11.5	10.2	4.45
½ to 1 inch	10.5	13.2	5.37	15.3	9.7	4.31
½ to ¾ inch	17.2	13.6	5.61	21.5	9.8	4.21
¼ to ½ inch	17.5	13.2	5.14	22.9	9.1	4.34
⅛ to ¼ inch	9.7	14.3	5.04	11.1	8.3	4.04
32 to ⅛ inch	4.5	15.7	5.00	3.4	9.0	3.82
48 to 32 inch	4.0	18.6	4.73	1.9	11.2	3.75
64 to 48 inch	2.7	21.1	4.60	.9	12.9	3.73
Through 64	4.3	18.8	4.80	1.2	19.8	4.15
Total average	100.0	14.1	5.27	100.0	9.6	4.31

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The effective cleaning of small sizes, shown by these figures, is particularly noteworthy. The cleanest washed coal is the one-eighth to one-fourth inch size, and the one-sixteenth to one-eighth inch size is cleaner than the average washed coal. The percentage by weight of these two sizes also indicates that this material is all present in the sample and that therefore the samples are representative.

Fairly satisfactory cleaning of all the fine sizes was obtained, with the exception of the very smallest product screened out through one-sixty-fourth-inch, which was dirtier than the average raw coal and about the same as the corresponding-size in the raw feed. The inference is that dust of this size only should be by-passed and added dry and untreated to the washed coal. Other factors, however, enter into this particular feature of the problem and may make it desirable to by-pass a still larger product including coarser material.

Although the fine sizes of coal were cleaned fairly effectively, there was a large loss of good coal of these sizes with the refuse. The effect on the average ash content of the addition of a very small percentage of material slightly higher in ash may be almost negligible and the advantages of lower moisture and lessened difficulties with sludge may make it advantageous. Table 11 shows the yields and ash contents of the final cleaned-coal product that would be obtained by screening out these fine sizes of raw coal and adding them dry to the jig-washed coal.

TABLE 11.—*Results of by-passing raw fines in treating the screenings*

Size by-passed	Combined yield of washed coal and raw fines, per cent	Ash, per cent
0 to $\frac{1}{4}$-inch dust	84.5	10.7
0 to $\frac{1}{8}$-inch dust	84.7	10.9
0 to $\frac{1}{16}$-inch dust	85.4	11.3
0 to $\frac{1}{32}$-inch dust	86.6	11.4

WASHING TESTS OF SLACK

Results obtainable by washing the slack separately on tables may be calculated by combining the table-washed coal (Table 12) with the jig-washed coal. These results show a combined yield of 83 per cent of washed coal with an average ash content of 9.2 per cent; or, if the table middling product is included, it shows a yield of 86.0 per cent with an ash content of 10.0 per cent, indicating an appreciable advantage in separate treatment of the slack coal because the table makes a more complete separation on the fine material below $\frac{1}{16}$ inch.

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TABLE 12.—*Table washing test on slack (0 to ¼-inch part of screenings), moisture-free basis*

Product	Weight	Feed	Ash	Sulphur
	Pounds	*Per cent*	*Per cent*	*Per cent*
Raw coal	191.5	100.0	17.0	4.80
Washed coal	150.3	78.4	8.1	3.97
Sludge loss by difference	3.6	1.9	19.8	4.15
Middlings	22.1	11.7	31.9	5.77
Refuse	15.5	8.1	74.3	13.51
Total and average	141.5	100.0	16.5	4.94
Washed coal and sludge	153.9	81.2	8.2	3.98
Washed coal and middlings	176.0	92.9	11.2	4.14

TESTS OF NUT COAL

The results obtained in washing the nut coal are shown in Table 13. The coal sample had necessarily been handled several times between the mine and the jig so that much of it was broken, accounting for the high percentage of hutch product. The separation at 1.60 specific gravity by the float-and-sink method yielded 83.8 per cent of float which had an ash content of 10.4 per cent; whereas separation by the jig method showed a 91.9 per cent yield (including the sludge) of coal containing 11.1 per cent ash. The reduction in sulphur obtained by washing the nut coal was better than that obtained with the screenings. The jig used in this test was designed for treating smaller coal than nut; and although certain alterations adapted it to treating coal of this size, a better separation can probably be made with a more suitably designed jig.

TABLE 13.—*Nut-coal jig test, moisture-free basis*

Product	Weight	Feed	Ash	Sulphur
	Pounds	*Per cent*	*Per cent*	*Per cent*
Raw coal	7,258.0	100.0	14.3	5.73
Washed coal	5,997.0	82.6	10.3	4.65
Sludge loss by difference	90.1	1.2	[a] 19.8	4.31
Middlings	374.0	5.2	18.9	6.36
Second hutch	207.0	2.9	15.6	4.07
Refuse	357.9	4.9	55.7	21.98
First hutch	232.0	3.2	38.4	6.23
Total and average	7,258.0	100.0	14.14	5.63
Washed coal plus sludge	6,087.1	83.8	10.4	4.64
Washed coal, sludge, middlings, and second hutch	6,668.1	91.9	11.1	4.72
Screen analysis of refuse:				
On ¼ inch		[b] 90.4	58.8	23.83
Through ¼ inch		[b] 9.6	26.0	4.61

[a] Determination is made for sample of washed coal slime through a one-sixty-fourth-inch mesh.
[b] Percentage of each size in refuse.

COMMERCIAL ADJUSTMENT OF OPERATIONS

By means of the washing-yield curves (Figs. 3, 4, and 5) drawn through the points determined by the washing tests, interpolation is possible, and the obtainable yield of washed coal of any desired quality may be estimated, although no such separation was actually made in the washing test.

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For example, one of the operators in this field wished to produce a clean coal containing about 10 per cent ash with a washer loss of not more than 15 to 20 per cent. When the nut coal was treated a yield of 78 per cent of coal of this quality, which is a somewhat smaller yield than the minimum specified as allowable, was obtained. In order that a separation at this point might be profitable, the increased market value of the washed coal must be enough to compensate for the 22 per cent shrinkage and cover the cost of washery operation.

Assuming that the market value of the raw nut coal is $2 per ton, the selling price per ton of washed coal necessary to show the same gross receipts is $2 divided by 78 per cent, or $2.56. The cost of operation of the washery, at about 15 cents per ton of raw coal treated, necessitates the expenditure of an additional 20 cents, which raises to $2.76 per ton the minimum washed-coal selling price which will show the same gross receipts as would the sale of the raw washery feed. Any higher selling price than this shows a profit on washery operation under these conditions. This example is merely hypothetical and is introduced to illustrate a method by which the economics of the operation may be calculated and to show how the washery may be adjusted to current market conditions. If the coal is sold on an ash or B. t. u. basis, with a premium for reduction in ash, the most profitable separation to make can be ascertained by similar calculations for various points on the washing yield curve.

For many mines the chief advantage gained through the use of a washery is its sales value, a fact particularly true in the central Illinois field where the small sizes of coal are ordinarily difficult to market. If, by cleaning the screenings and nut coal, steadier operation is made possible, the washery may be profitable even though it shows a loss on the coal actually treated.

CONCLUSIONS

With the float-and-sink method as a standard which shows a yield of 89.5 per cent of float coal with a 10 per cent ash content, operation of the jig and table together for the screenings shows an efficiency of $\frac{86}{89.5}$ or 96 per cent, compared with $\frac{84.5}{92.5}$ or 91 per cent for the jig test of unsized screenings. Table 14 gives the efficiency figures for all the tests and all the separations that were considered practicable. These efficiency numbers are the ratios of yield of washed coal to yield of float coal of the same ash content, read from the yield-ash curves plotted by means of the specific gravity analyses. They are given as a measure of completeness of the mechanical separation obtained in each test; the highest efficiency number does

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not necessarily indicate the most profitable operation, as many other factors enter into the calculation besides completeness of separation with regard to specific gravity.

TABLE 14.—*Efficiency ratios for the washing tests computed by the yield-curve method*

Operation:	Efficiency ratio
Preliminary jig test, preparation of washed coal and sludge combined	$\frac{79.2}{93.8} = 0.84$
Preliminary jig test, washed coal, sludge, middling, and second hutch combined	$\frac{89.1}{94.2} = .94$
Final jig test, washed coal and sludge combined	$\frac{84.5}{92.5} = .91$
Final jig test, washed coal, sludge, middling, and second hutch combined	$\frac{92.1}{94.5} = .97$
Final jig test and table test combined—jig-washed coal, table-washed coal, and sludge	$\frac{83.0}{84.5} = .98$
Jig-washed coal, table-washed coal, sludge, and middlings combined	$\frac{86.0}{89.5} = .96$
Table test, washed coal	$\frac{81.2}{84.5} = .96$
Table-washed coal and middlings combined	$\frac{92.9}{93.0} = .99$
Nut-coal jig test, washed coal, and sludge combined	$\frac{83.8}{92.0} = .91$
Washed nut coal, sludge, middlings, and second hutch combined	$\frac{91.9}{94.0} = .97$

If it is assumed that this mine is representative of central Illinois conditions, the investigation indicates that cleaning the screenings and nut-coal sizes is practicable at mines of this field working the No. 6 seam, and that a cleaned coal product containing 10 to 11 per cent ash may be expected. This ash content is approximately that of the average face sample, excluding all segregated impurities that it is practicable to pick out in cutting a face sample.

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